US009216571B2

(12) **United States Patent**
Naito et al.

(10) **Patent No.: US 9,216,571 B2**
(45) **Date of Patent: Dec. 22, 2015**

(54) **LIQUID DISCHARGE APPARATUS AND LIQUID DISCHARGE METHOD**

(71) Applicant: **Brother Kogyo Kabushiki Kaisha**, Nagoya-shi, Aichi-Ken (JP)

(72) Inventors: **Kyohei Naito**, Nagoya (JP); **Mizuyo Takebayashi**, Nagoya (JP); **Keiji Kura**, Chita (JP)

(73) Assignee: **Brother Kogyo Kabushiki Kaisha**, Aichi-ken (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/455,140**

(22) Filed: **Aug. 8, 2014**

(65) **Prior Publication Data**

US 2015/0091962 A1 Apr. 2, 2015

(30) **Foreign Application Priority Data**

Sep. 30, 2013 (JP) 2013-203890

(51) **Int. Cl.**
B41J 29/38 (2006.01)
B41J 2/045 (2006.01)
B41J 2/14 (2006.01)

(52) **U.S. Cl.**
CPC ***B41J 2/04588*** (2013.01); ***B41J 2/04581*** (2013.01); ***B41J 2/04593*** (2013.01); ***B41J 2/14233*** (2013.01); *B41J 2002/14258* (2013.01); *B41J 2002/14491* (2013.01)

(58) **Field of Classification Search**
CPC B41J 2002/14491; B41J 2/14233; B41J 2/04581; B41J 2/14209; B41J 2/04588; B41J 2/04541; B41J 2/14201; B41J 2002/14258
USPC 347/9, 10, 11, 68, 70, 71
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2013/0235122 A1* 9/2013 Hiwada et al. 347/54

FOREIGN PATENT DOCUMENTS

JP 2012-206442 10/2012

* cited by examiner

Primary Examiner — Jannelle M Lebron
(74) *Attorney, Agent, or Firm* — Frommer Lawrence & Haug LLP

(57) **ABSTRACT**

A liquid discharge apparatus is provided, comprising a channel structure; a piezoelectric actuator which has a plurality of individual electrodes, a common electrode, and a piezoelectric layer sandwiched between the individual electrodes and the common electrode; and a driving device which drives the piezoelectric actuator. The driving device outputs an individual driving signal which causes a change of an electric potential of the individual electrode, to the individual electrode corresponding to the nozzle for discharging the liquid. Further, the driving device outputs a common driving signal which causes a change of an electric potential of the common electrode in synchronization with the change of the electric potential of the individual electrode into which the individual driving signal is inputted, to the common electrode.

10 Claims, 10 Drawing Sheets

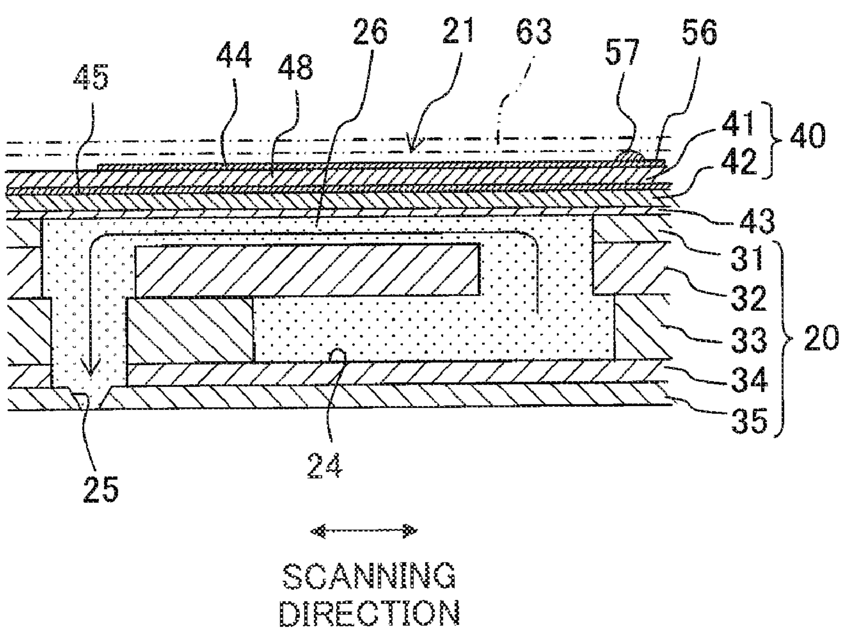


Fig. 1

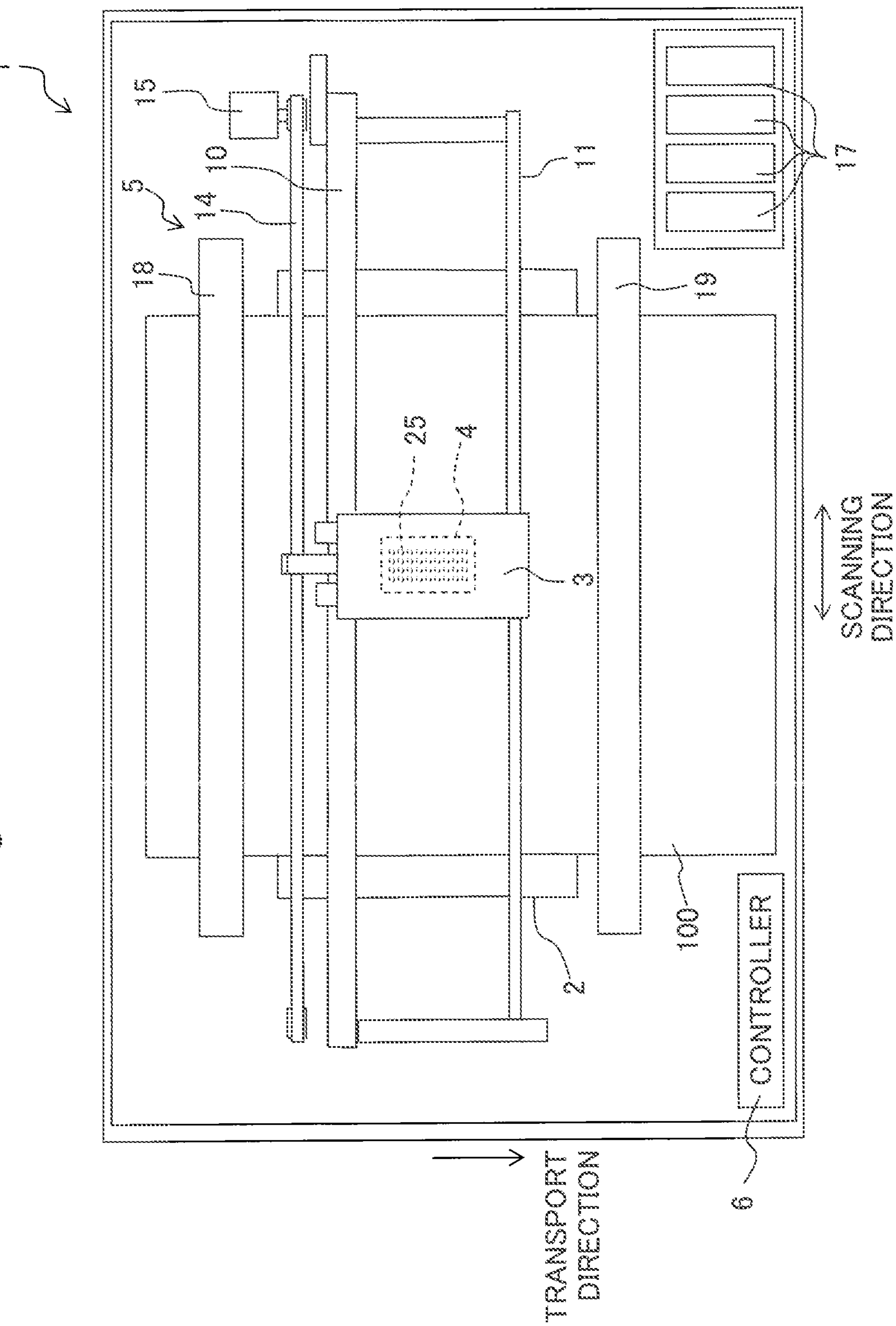

1
15
10
11
5
14
17
18
19
25
4
3
SCANNING DIRECTION
2
100
CONTROLLER
6
TRANSPORT DIRECTION

Fig. 2

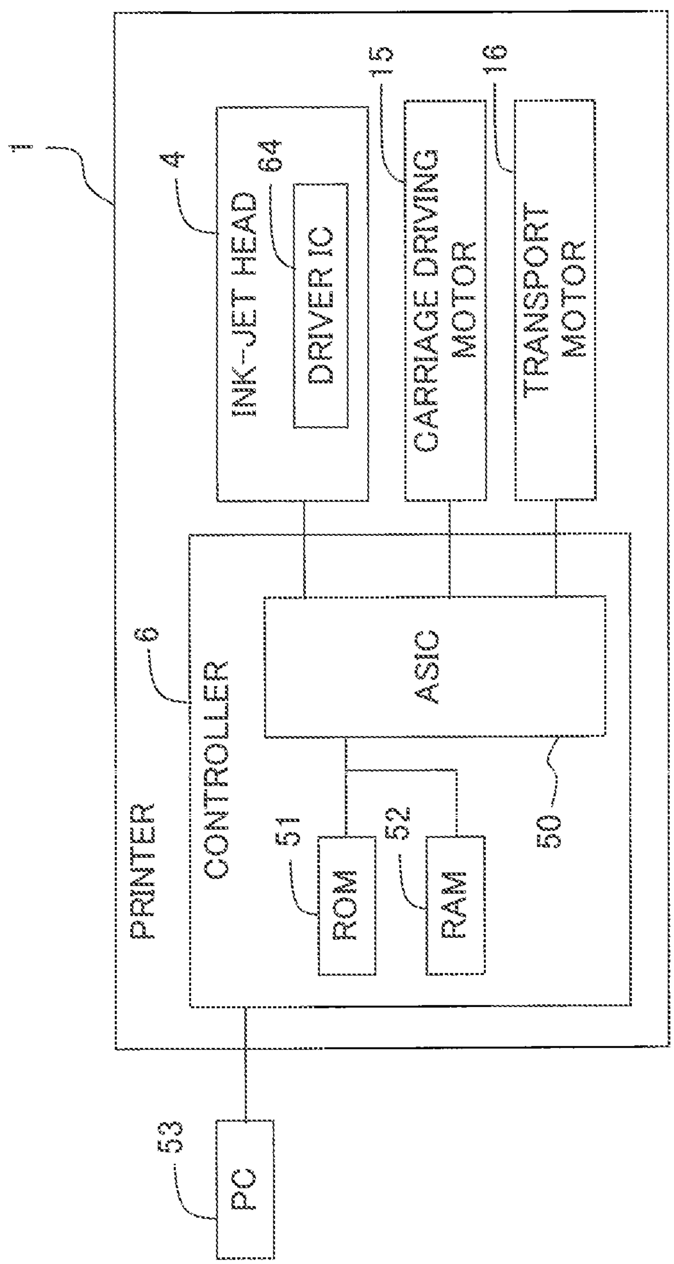

1
PRINTER
4
INK-JET HEAD
64
DRIVER IC
15
CARRIAGE DRIVING MOTOR
16
TRANSPORT MOTOR
6
CONTROLLER
ASIC
50
51
ROM
52
RAM
53
PC

Fig. 3

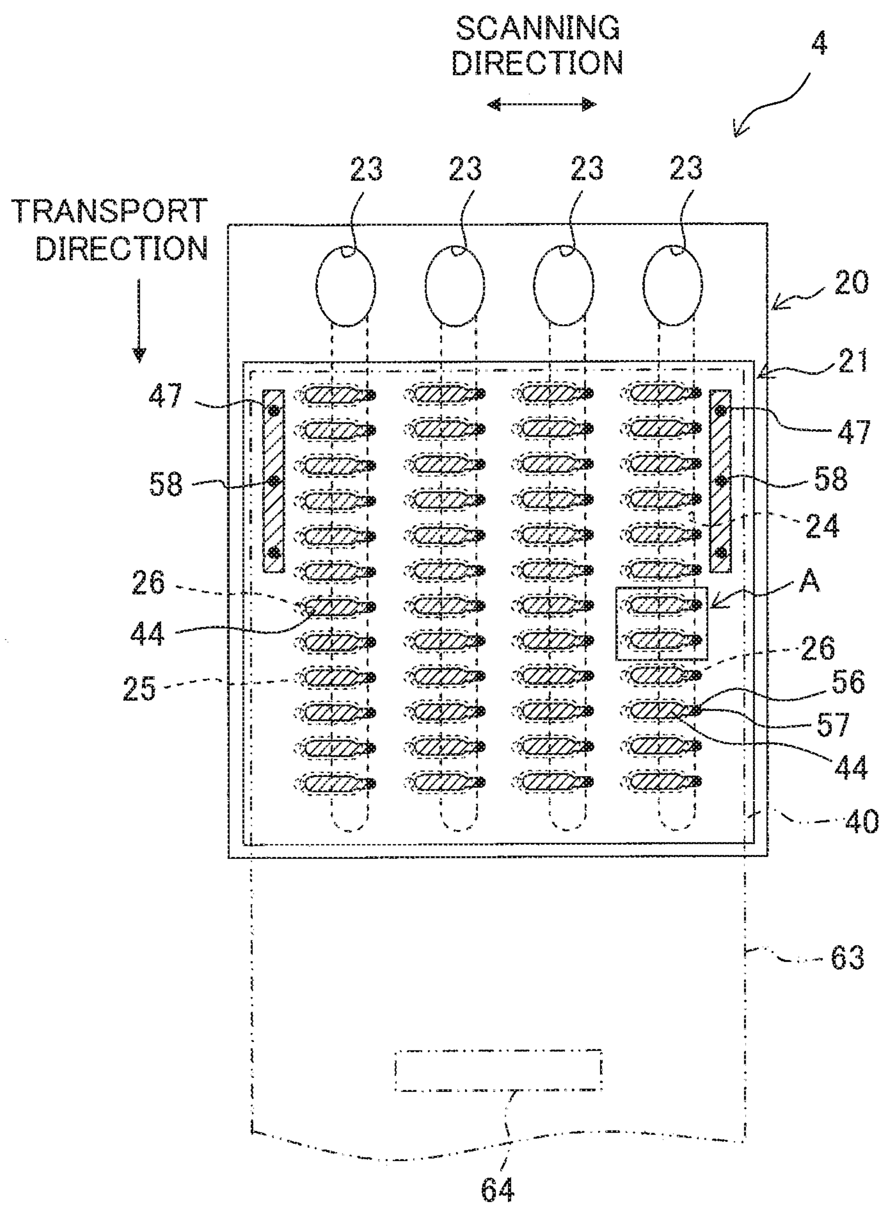

SCANNING
DIRECTION
4
23
23
23
23
TRANSPORT
DIRECTION
20
21
47
47
58
58
24
26
A
44
26
25
56
57
44
40
63
64

Fig. 4

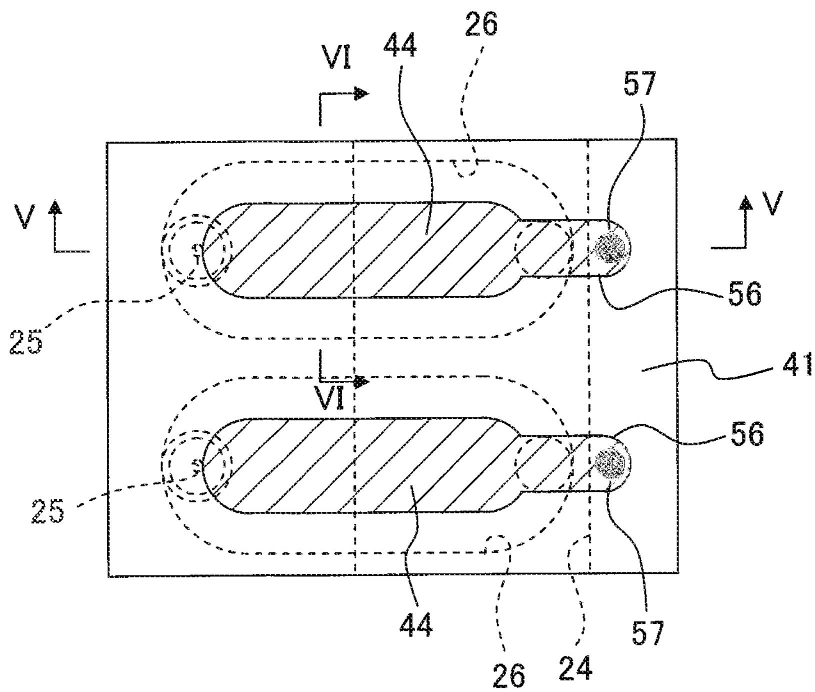

VI
44
26
57
V
V
25
56
41
VI
56
25
44
57
26
24

Fig. 5

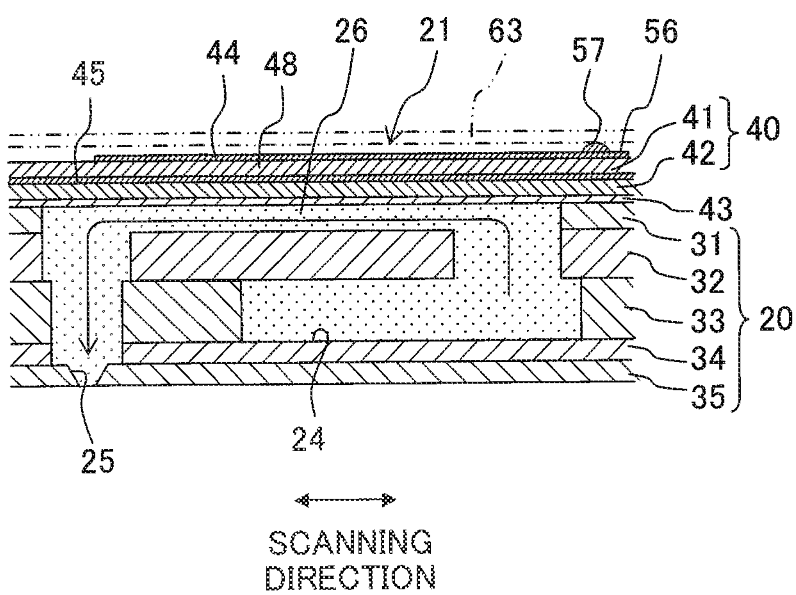

45
44
48
26
21
63
57
56
41
40
42
43
31
32
33
20
34
35
25
24
SCANNING
DIRECTION

Fig. 6

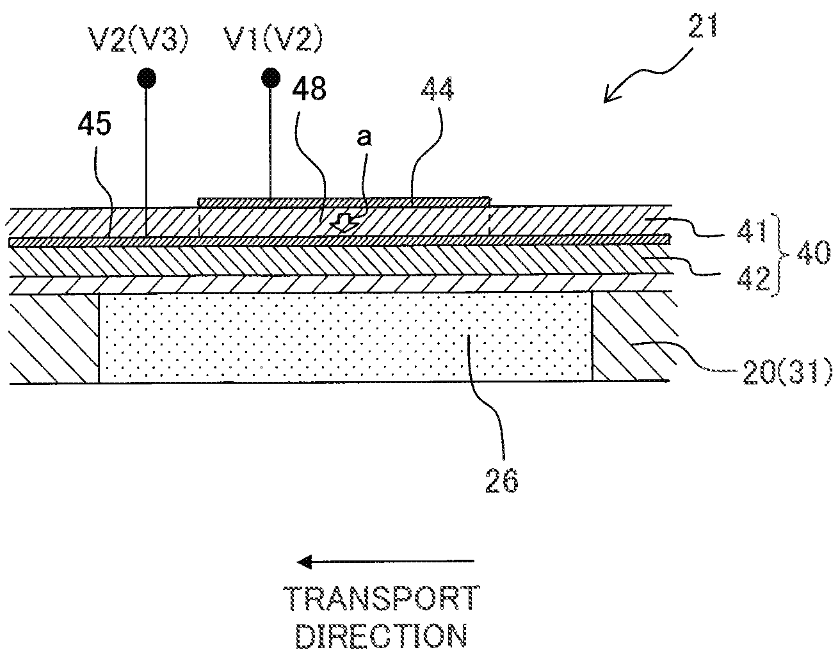


Fig. 7

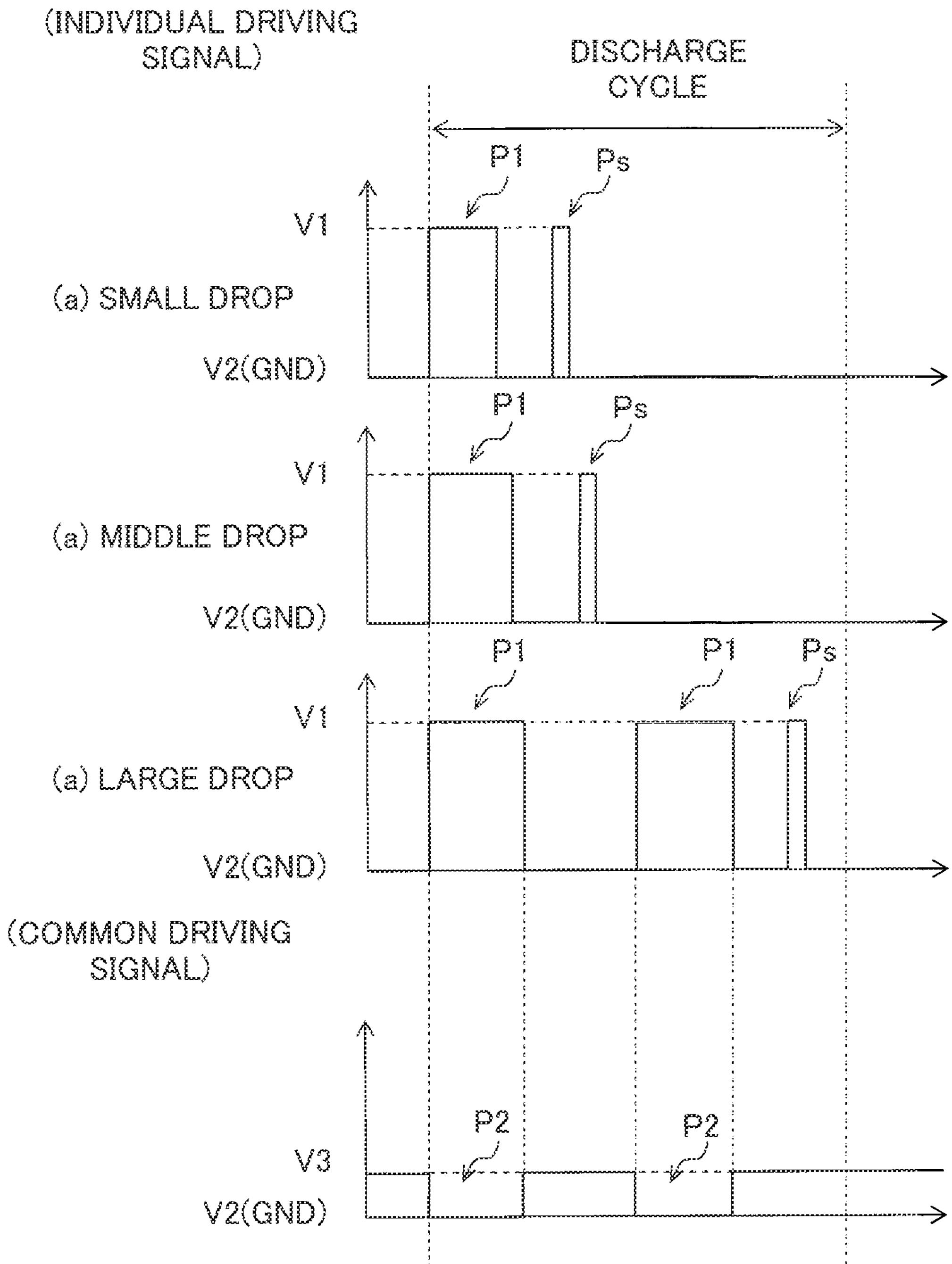

(INDIVIDUAL DRIVING SIGNAL)
DISCHARGE CYCLE
P1
Ps
V1
(a) SMALL DROP
V2(GND)
P1
Ps
V1
(a) MIDDLE DROP
V2(GND)
P1
P1
Ps
V1
(a) LARGE DROP
V2(GND)
(COMMON DRIVING SIGNAL)
P2
P2
V3
V2(GND)

Fig. 8A

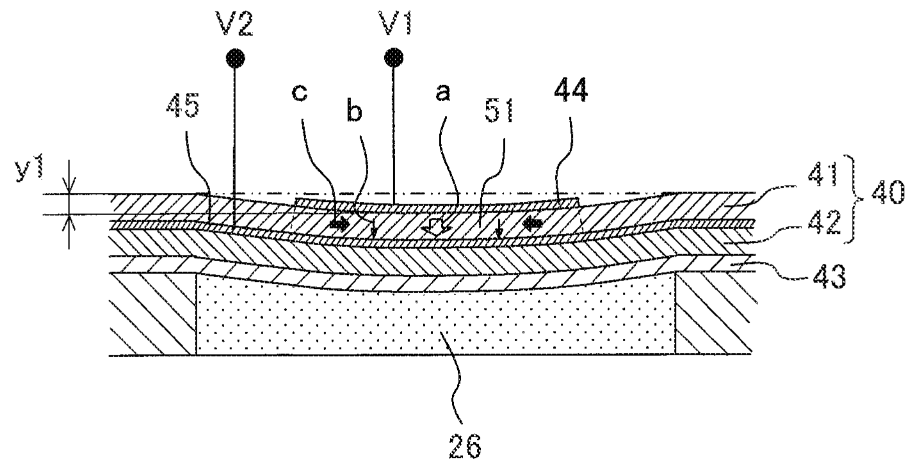

V2
V1
45
c
b
a
51
44
y1
41
40
42
43
26

Fig. 8B

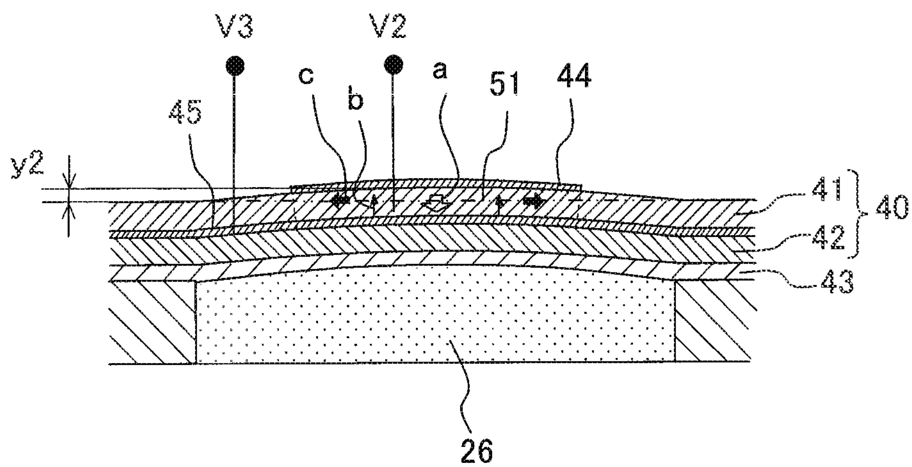

V3
V2
c
b
a
51
44
45
y2
41
40
42
43
26

Fig. 9

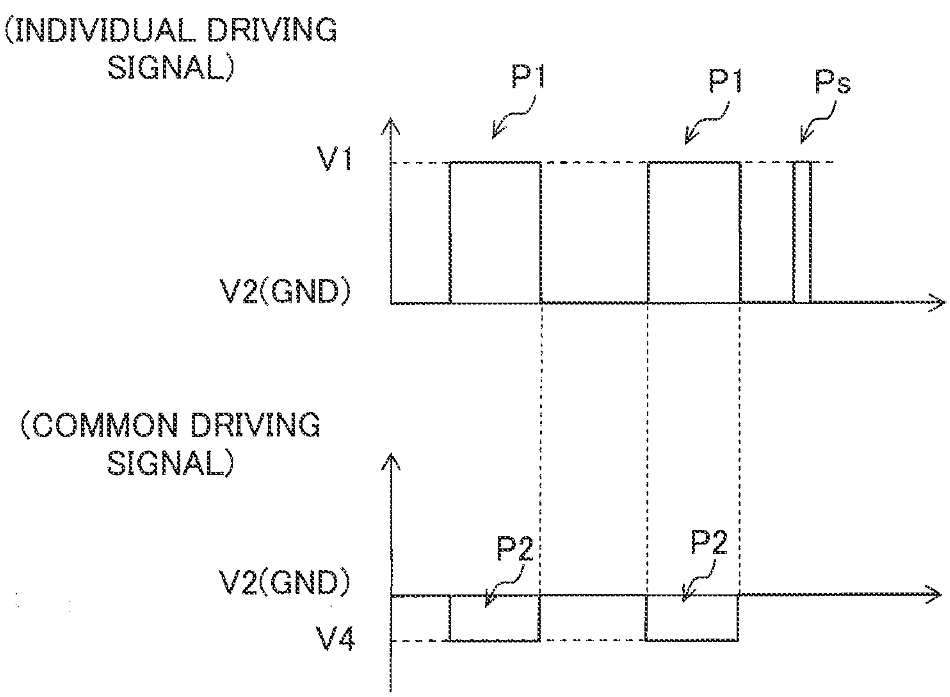

(INDIVIDUAL DRIVING SIGNAL)
P1
P1
Ps
V1
V2(GND)
(COMMON DRIVING SIGNAL)
P2
P2
V2(GND)
V4

Fig. 10

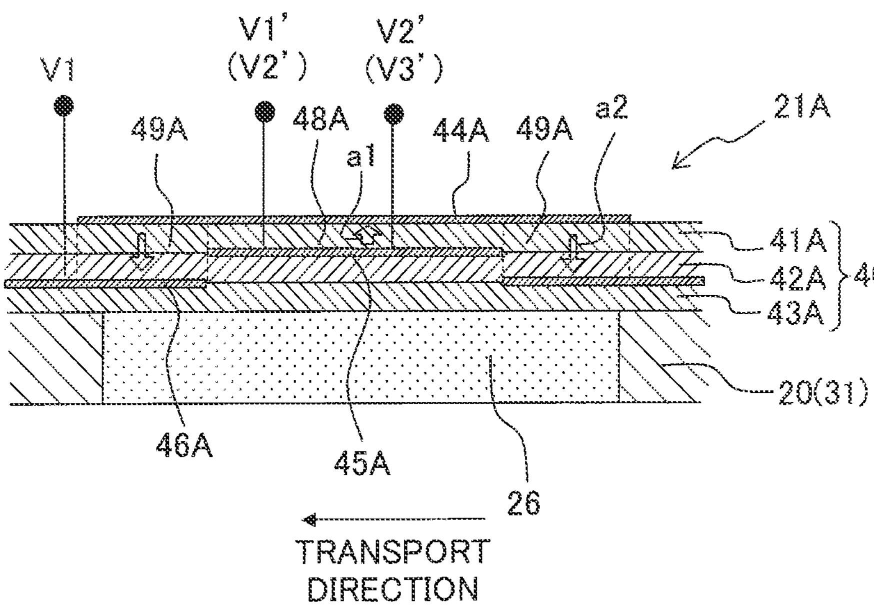

V1
V1'
(V2')
V2'
(V3')
49A
48A
a1
44A
49A
a2
21A
41A
42A
43A
40
20(31)
46A
45A
26
TRANSPORT DIRECTION

Fig. 11

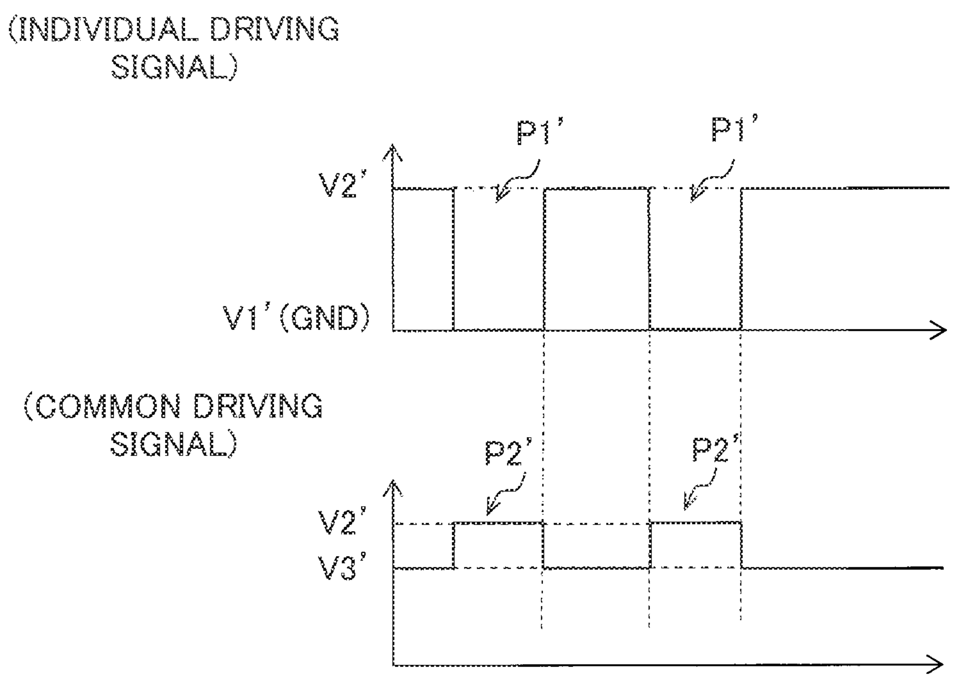

(INDIVIDUAL DRIVING SIGNAL)
P1'
P1'
V2'
V1'(GND)
(COMMON DRIVING SIGNAL)
P2'
P2'
V2'
V3'

Fig. 12A

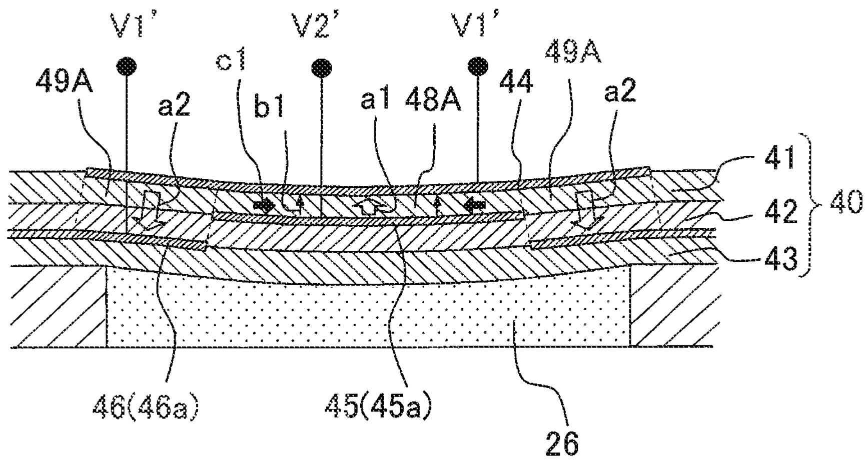
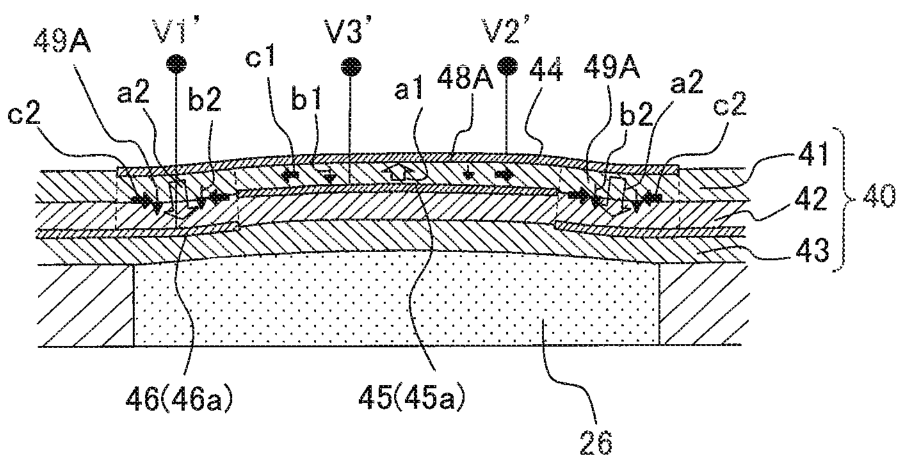


Fig. 12B



LIQUID DISCHARGE APPARATUS AND LIQUID DISCHARGE METHOD

CROSS REFERENCE TO RELATED APPLICATION

The present application claims priority from Japanese Patent Application No. 2013-203890, filed on Sep. 30, 2013, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field of the Invention

The present invention relates to a liquid discharge apparatus and a liquid discharge method based on the use of the same.

2. Description of the Related Art

An ink-jet head is known as a liquid discharge apparatus, the ink-jet head comprising a channel unit which is formed with ink channels including a plurality of nozzles, and a piezoelectric actuator which discharges ink from the plurality of nozzles respectively. The channel unit has a plurality of pressure chambers which are communicated with the plurality of nozzles respectively. The piezoelectric actuator is joined to the channel unit so that the plurality of pressure chambers are covered therewith.

The piezoelectric actuator has a piezoelectric layer, a plurality of individual electrodes, and a common electrode. The plurality of individual electrodes are provided while corresponding to the plurality of pressure chambers respectively on a surface of the piezoelectric layer disposed on the side opposite to the channel unit. The common electrode is arranged so that the common electrode is commonly opposed to the plurality of individual electrodes with the piezoelectric layer intervening therebetween, on a surface of the piezoelectric layer disposed on the side of the channel unit. The plurality of individual electrodes are connected to a driver IC for driving the piezoelectric actuator via a wiring member. Further, the common electrode is always retained at the ground electric potential.

The driver IC outputs the driving signal to the individual electrode corresponding to the nozzle from which the ink is to be discharged so that the electric potential of the individual electrode is switched between the driving electric potential and the ground electric potential. Accordingly, the voltage, which is applied to the portion of the piezoelectric layer interposed between the individual electrode and the common electrode (hereinafter referred to as "piezoelectric element" as well), is changed. In this situation, the contraction occurs in the piezoelectric element, and the piezoelectric actuator is deformed so that the piezoelectric actuator is warped or bent. Accordingly, the volume of the pressure chamber is changed, and the discharge energy is applied to the ink contained in the pressure chamber.

SUMMARY

In the piezoelectric actuator described above, the larger the deformation amount of each of the piezoelectric elements is, the larger the volume change of the corresponding pressure chamber is, wherein it is possible to apply the larger discharge energy to the liquid. However, when only the electric potential of the individual electrode is changed by the driver IC as in the piezoelectric actuator as described above, there has been a limit even if it is intended to increase the deformation amount of the piezoelectric element.

An object of the present teaching is to provide a liquid discharge apparatus which makes it possible to increase the deformation of each of piezoelectric elements of a piezoelectric actuator, and a liquid discharge method which is based on the use of the same.

According to a first aspect of the present teaching, there is provided a liquid discharge apparatus for discharging a liquid, including:

a channel structure in which a plurality of liquid channels including a plurality of nozzles is formed;

a piezoelectric actuator which is formed on the channel structure and which is configured so that discharge energy is applied to the liquid contained in the nozzles to discharge the liquid from the plurality of nozzles respectively, the piezoelectric actuator including:

- a plurality of individual electrodes which correspond to the plurality of nozzles respectively and each of which is configured to be subjected to an electric potential, separately;
- a common electrode which is configured to be subjected to a common electric potential; and
- a piezoelectric layer which is sandwiched between each of the individual electrodes and the common electrode; and

a driving device which is configured to drive the piezoelectric actuator, the driving device being configured so that:

- an individual driving signal, which causes a change of an electric potential of the individual electrodes, is output to each of the individual electrodes corresponding to one of the nozzles for discharging the liquid; and
- a common driving signal, which causes a change of an electric potential of the common electrode in synchronization with the change of the electric potential of the individual electrodes into which the individual driving signal is input, is output to the common electrode.

In the present teaching, when the liquid is discharged from a certain nozzle, the driving device outputs the individual driving signal to the individual electrode corresponding to the nozzle for discharging the liquid. On the other hand, the driving device also outputs the common driving signal to the common electrode so that the electric potential of the common electrode is changed corresponding to the change of the electric potential of the individual electrode. Accordingly, it is possible to deform the piezoelectric element more greatly. In the present teaching, the phrase "common electrode is commonly provided for the plurality of piezoelectric elements" means that the same electric potential is applied to portions of the common electrode corresponding to the plurality of piezoelectric elements respectively.

According to a second aspect of the present teaching, there is provided a liquid discharge method for discharging liquid by using a liquid display apparatus, the liquid display apparatus including:

a channel structure in which a plurality of liquid channels including a plurality of nozzles is formed; and

a piezoelectric actuator which is formed on the channel structure and which is configured so that discharge energy is applied to the liquid contained in the nozzles to discharge the liquid from the plurality of nozzles respectively, the piezoelectric actuator including:

a plurality of individual electrodes which correspond to the plurality of nozzles respectively and each of which is configured to be subjected to an electric potential, separately;

- a common electrode which is configured to be subjected to a common electric potential; and
- a piezoelectric layer which is sandwiched between each of the individual electrodes and the common electrode; and

the method including:

outputting an individual driving signal which causes a change of an electric potential of the individual electrodes, to each of the individual electrodes corresponding to one of the nozzles for discharging the liquid; and

outputting a common driving signal which causes a change of an electric potential of the common electrode in synchronization with the change of the electric potential of the individual electrodes into which the individual driving signal is input, to the common electrode.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a schematic plan view illustrating a printer of an embodiment of the present teaching.

FIG. **2** shows a block diagram schematically illustrating an electric arrangement of the printer.

FIG. **3** shows a plan view illustrating an inkjet head.

FIG. **4** shows an enlarged view illustrating Portion A shown in FIG. **3**.

FIG. **5** shows a sectional view taken along a line V-V shown in FIG. **4**.

FIG. **6** shows a sectional view taken along a line VI-VI shown in FIG. **4**.

FIG. **7** shows waveforms of individual driving signals and a common driving signal.

FIGS. **8**A and **8**B illustrate the operation of a piezoelectric actuator.

FIG. **9** shows waveforms of an individual driving signal and a common driving signal of a modified embodiment.

FIG. **10** shows a sectional view illustrating a piezoelectric actuator of another modified embodiment,

FIG. **11** shows waveforms of an individual driving signal and a common driving signal concerning the piezoelectric actuator shown in FIG. **10**.

FIGS. **12**A and **12**B illustrate the operation of the piezoelectric actuator shown in FIG. **10**.

DESCRIPTION OF THE EMBODIMENTS

Next, an embodiment of the present teaching will be explained. An explanation will be made with reference to FIGS. **1** and **2** about a schematic arrangement of a printer **1**. In the following description, the front side of the paper surface of FIG. **1** is defined as “upward”, and the back side of the paper surface is defined as “downward”,

Schematic Arrangement of Printer

As shown in FIG. **1**, the printer **1** includes, for example, a platen **2**, a carriage **3**, an ink-jet head **4**, a transport mechanism **5**, and a controller **6**.

Recording paper **100** as a recording medium is placed on the upper surface of the platen **2**. The carriage **3** is configured so that the carriage **3** is reciprocatively movable in the scanning direction along two guide rails **10**, **11** in an area opposed to the platen **2**. An endless belt **14** is connected to the carriage **3**. The endless belt **14** is driven by a carriage driving motor **15**, and thus the carriage **3** is moved in the scanning direction.

The ink-jet head **4** is attached to the carriage **3**, and the ink-jet head **4** is movable in the scanning direction together with the carriage **3**. The ink-jet head **4** is connected by the tubes (not shown) to ink cartridges **17** of four colors (for example, black, yellow, cyan, and magenta) installed to the printer **1**. Further, a plurality of nozzles **25** are formed on the lower surface of the inkjet head **4** (surface disposed on the back side of the paper-plane of FIG. **1**). The four color inks, which are supplied from the ink cartridges **17**, are discharged by the inkjet head **4** from the plurality of nozzles **25** toward the recording paper **100** placed on the platen **2**.

The transport mechanism **5** has two transport rollers **18**, **19** which are arranged to interpose the platen **2** in the transport direction therebetween. The transport rollers **18**, **19** are driven in synchronization with each other by a transport motor **16** (see FIG. **2**). The transport mechanism **5** transports the recording paper **100** placed on the platen **2** in the transport direction by means of the two transport rollers **18**, **19**.

As shown in FIG. **2**, the controller **6** includes, for example, Application Specific Integrated Circuit **50** (ASIC **50**), and Read Only Memory **51** (ROM **51**) and Random Access Memory **52** (RAM **52**) which are connected to ASIC **50**. Further, the controller **6** is connected to PC **53** as an external apparatus so that the data communication can be performed.

The controller **6** executes various processes including, for example, the printing on the recording paper **100** by means of ASIC **50** in accordance with a program stored in ROM **51**. For example, in the printing process, the controller **6** controls, for example, the inkjet head **4**, the carriage driving motor **15**, and the transport motor **16** on the basis of a printing instruction inputted from PC **53** to print, for example, an image on the recording paper **100**. Specifically, the controller **6** alternately causes the execution of the ink discharge operation in which the inks are discharged while moving the inkjet head **4** in the scanning direction together with the carriage **3** and the execution of the transport operation in which the recording paper **100** is transported by a predetermined amount in the transport direction by means of the transport rollers **18**, **19**. The foregoing explanation refers to an example in which the controller **6** performs or executes various processes by means of ASIC **50**. However, the present teaching is not limited thereto. The construction of the controller **6** can be appropriately changed. For example, the controller **6** may be realized by any hardware configuration. For example, the function may be shared by two or more ASIC’s to realize the process.

Details of Inkjet Head

Next, the ink-jet head **4** will be explained. In FIGS. **3** and **5**, COF **63**, which is connected to a piezoelectric actuator **21**, is schematically depicted by two-dot chain lines. In FIG. **6**, the channel structure of those disposed under or below a pressure chamber **26**, which is shown in FIG. **5**, is omitted from the illustration. As shown in FIGS. **3** to **6**, the inkjet head **4** includes a channel unit **20**, the piezoelectric actuator **21**, and a driver IC **64**.

Construction of Channel Unit

As shown in FIG. **5**, the channel unit **20** is formed by mutually stacking five plates **31** to **35** which are formed with channel-forming holes respectively. The five plates **31** to **35** are stacked so that the respective channel-forming holes are communicated with each other. In this way, ink channels are formed in the channel unit **20** as described below.

As shown in FIG. **3**, four ink supply holes **23**, which are connected to the four ink cartridges **17** (see FIG. **1**), are formed on the upper surface of the channel unit **20**. Four manifolds **24**, which are connected to the four ink supply holes **23** respectively, are formed in the channel unit **20**. The four color inks contained in the four ink cartridges **17** are supplied respectively to the four manifolds **24** via the four ink supply holes **23**. The four manifolds **24** extend in the transport direction respectively.

A plurality of nozzles **25** are formed in a plate **35** disposed at the lowermost layer of the channel unit **20**. A plurality of pressure chambers **26** are formed in a plate **31** disposed at the uppermost layer. As shown in FIG. **3**, the plurality of nozzles **25** are arranged in the transport direction on the lower surface of the channel unit **20** (surface disposed on the back side of the paper-plane of FIG. **3**) to form four arrays of nozzle arrays corresponding to the four manifolds **24** respectively.

The plurality of pressure chambers **26** are arranged in a planar form along the upper surface of the channel unit **20**. The plurality of pressure chambers **26** are covered, at upper positions, with a piezoelectric member **40** of the piezoelectric actuator **21** joined to the upper surface of the channel unit **20**. Further, the plurality of pressure chambers **26** are arranged in four arrays corresponding to the four manifolds **24** and the four arrays of nozzle arrays. Each of the pressure chambers **26** has a substantially an elliptical shape which is elongated in the scanning direction as viewed in a plan view. One end of each of the pressure chambers **26** in the longitudinal direction is communicated with the manifold **24**, and the other end in the longitudinal direction is communicated with the nozzle **26**. Accordingly, as shown in FIG. **5**, a plurality of individual ink channels, which are branched from the manifolds **24** to arrive at the nozzles **25** via the pressure chambers **26**, are formed in the channel unit **20**.

Construction of Piezoelectric Actuator

The piezoelectric actuator **21** is joined to the upper surface of the channel unit **20** so that the plurality of pressure chambers **26** are covered therewith. As shown in FIGS. **3** to **6**, the piezoelectric actuator **21** includes an ink sealing film **43**, the piezoelectric member **40** which is formed by two piezoelectric layers **41**, **42**, a plurality of individual electrodes **44**, and a common electrode **45**.

The ink sealing film **43** is a thin film formed of a material having low ink permeability including, for example, a metal material such as stainless steel or the like. The ink sealing film **43** is joined to the upper surface of the channel unit **20** so that the plurality of pressure chambers **26** are covered therewith.

Each of the two piezoelectric layers **41**, **42** for constructing the piezoelectric member **40** is composed of a piezoelectric material containing a main component of lead titanate zirconate as mixed crystal of lead titanate and lead zirconate. The piezoelectric layers **41**, **42** are arranged on the upper surface of the ink sealing film **43** in a state of being mutually stacked. The piezoelectric member **40** can be obtained, for example, such that the individual electrodes **44** and the common electrode **45** are formed, for example, by means of the printing on two unsintered green sheets, and then the two green sheets are stacked and sintered. However, the method for forming the piezoelectric member **40** is not limited to the method described above, which may be appropriately changed.

The plurality of individual electrodes **44** are arranged on the upper surface of the piezoelectric layer **41** disposed at the upper layer. In particular, as shown in FIGS. **3** to **6**, the respective individual electrodes **44** are arranged in the areas of the upper surface of the piezoelectric layer **41** opposed to central positions of the pressure chambers **26**. The plurality of individual electrodes **44** are arranged in the transport direction corresponding to the plurality of pressure chambers **26** to constitute four arrays of individual electrode arrays. Individual terminals **56** are led out from the respective individual electrodes **44**. Further, bumps **57**, each of which is composed of a conductive material such as gold or the like, are provided at end portions of the individual terminals **56**. As shown in FIG. **5**, COF **63**, which is a wiring member, is pressed against and joined to the bumps **57**. Accordingly, the individual terminals **56** are electrically connected to the wirings formed on COF **63** via the humps **57**.

The common electrode **45** is arranged between the two piezoelectric layers **41**, **42**, and the common electrode **45** is provided commonly for the plurality of individual electrodes **44**. In particular, the common electrode **45** is commonly opposed to the plurality of individual electrodes **44** with the piezoelectric layer **41** intervening therebetween. Accordingly, the same electric potential is applied to all of a plurality of electrode portions of the common electrode **45** opposed to the plurality of individual electrodes **44** respectively.

As shown in FIG. **3**, two leading electrodes **47** are provided respectively at both end portions in the scanning direction of the upper surface of the piezoelectric layer **41** disposed at the upper layer. The two leading electrodes **47** are in conduction with the common electrode **45** disposed between the two piezoelectric layers **41**, **42** via a plurality of plated through-holes (not shown) formed through the piezoelectric layer **41**. Further, a plurality of humps **58** are provided on the leading electrodes **47**. The two leading electrodes **47** are electrically connected to the wirings formed on COF **63** via the plurality of bumps **58**.

The portion of the piezoelectric layer **41**, which is interposed between the individual electrode **44** and the common electrode **45**, is polarized downwardly in the thickness direction, i.e., in the direction directed from the individual electrode **44** to the common electrode **45**, as indicated by the blanked arrow a in FIG. **6**. The polarized portion of the piezoelectric layer **41** is contracted or elongated in the in-plane direction of the piezoelectric layer **41** which is the direction perpendicular to the polarization direction and the electric field direction when the electric field is allowed to act in the direction parallel to the polarization direction. The portion of the piezoelectric layer **41**, which is interposed between the individual electrode **44** and the common electrode **45**, is hereinafter referred to as "piezoelectric element **48**". The plurality of piezoelectric elements **48**, which correspond to the plurality of pressure chambers **26** respectively, exist in the piezoelectric layer **41**.

Driver IC

Next, the driver IC **64** will be explained. As shown in FIG. **3**, the driver IC **64** is mounted on COF **63** which is the wiring member. Further, COF **63** is connected to the plurality of bumps **57**, **58** (see FIGS. **3** and **5**) formed on the upper surface of the piezoelectric layer **41**. Accordingly, the driver IC **64** is connected to the plurality of individual electrodes **44** and the common electrode **45** of the piezoelectric actuator **21** via the wirings formed on COF **63**.

The driver IC **64** outputs an individual driving signal to the individual electrode **44** corresponding to the nozzle **25** for discharging the ink so that the electric potential of the individual electrode **44** is changed. Further, the driver IC **64** also outputs a common driving signal to the common electrode **45** so that the electric potential of the common electrode **45** is changed. In this way, the electric potentials of the individual electrode **44** and the common electrode **45** are changed by the driver IC **64**. Thus, the electric field in the thickness direction is allowed to act on the piezoelectric element **48** interposed between the individual electrode **44** and the common electrode **45** so that the piezoelectric deformation is caused in the piezoelectric element **48**.

The discharge cycle shown in FIG. **7** indicates the time for forming one dot (pixel) on the recording paper **100** by means of one nozzle **25**. As shown in FIG. **7**, the driver IC **64** of the embodiment of the present teaching is configured so that three types of the individual driving signals, which correspond to three types of ink discharge amounts (small drop, middle drop, large drop) respectively, can be generated in order to realize the gradation printing by changing the amount of the ink discharged from one nozzle **25**. The driver IC **64** generates and outputs one type of the signal selected from the three types of the individual driving signals, with respect to the individual electrode **44** corresponding to the nozzle **25** for discharging the ink, on the basis of the control signal fed from the controller **6**.

The three types of the individual driving signals have individual discharge pulses P**1** respectively. When the individual discharge pulse P**1** is applied to the individual electrode **44**, the electric potential of the individual electrode **44** is thereby switched in an order of "second electric potential V**2**→first electric potential V**1**→second electric potential V**2**". In the embodiment of the present teaching, the second electric potential V**2** is the ground electric potential (GND), and the first electric potential V**1** is a positive electric potential higher than the second electric potential V**2**. As will be described later on as well, the piezoelectric element **48** is deformed in accordance with the electric potential change of the individual electrode **44** caused by the application of the individual discharge pulse P**1**, and thus the pressure wave is generated in the pressure chamber **26** to apply the discharge energy to the ink. The three types of the individual driving signals have stabilizing pulses Ps in addition to the individual discharge pulses P**1**. The stabilizing pulse Ps is a pulse which is output after the individual discharge pulse P**1** and which has a pulse width smaller than that of the individual discharge pulse P**1**. The stabilizing pulse Ps is the pulse which is applied in order to attenuate the pressure fluctuation of the ink caused by the individual discharge pulse P**1**.

Each of the individual driving signal for the small drop and the individual driving signal for the middle drop has one individual discharge pulse P**1** in one discharge cycle. However, the pulse width of the individual discharge pulse P**1** of the individual driving signal for the small drop is smaller than the pulse width of the individual discharge pulse P**1** of the individual driving signal for the middle drop. On account of the difference in the pulse width, the ink discharge amount from the nozzle **25**, which is provided when the individual driving signal for the small drop is output to the individual electrode **44**, is smaller than that provided when the individual driving signal for the middle drop is output. Further, the individual driving signal for the large drop has the two individual discharge pulses P**1**. Accordingly, the ink discharge amount from the nozzle **25**, which is provided when the individual driving signal for the large drop is output to the individual electrode **44**, is larger than those provided when the individual driving signals for the small drop and the middle drop are output. The waveforms of the individual driving signals shown in FIG. **7** are examples in a persistent manner. The waveform can be appropriately changed depending on the amount of the ink to be discharged, for example, in relation to the number of the individual discharge pulse(s) P**1**, the pulse width, and/or the presence or absence of the stabilizing pulse Ps. For example, it is not necessarily indispensable that the number of the individual discharge pulses P**1** of the individual driving signal for the large drop should be two. It is also allowable that the number is one or three or more.

Further, the driver IC **64** generates one type of the common driving signal. The common driving signal is a signal which changes the electric potential of the common electrode **45** in accordance with the change of the electric potential of the individual electrode **44** to which the individual driving signal for the large drop is output.

The common driving signal will be specifically explained. As shown in FIG. **7**, the common driving signal has two common discharge pulses P**2** which correspond to the two individual discharge pulses P**1** of the individual driving signal for the large drop. When the common discharge pulses P**2** are applied to the common electrode **45**, the electric potential of the common electrode **45** is switched thereby in an order of "third electric potential V**3**→second electric potential V**2**→third electric potential V**3**". The third electric, potential V**3** is an electric potential which is intermediate between the first electric potential V**1** and the second electric potential V**2**. That is, the magnitude correlation among the three types of the electric potentials V**1**, V**2**, V**3** is given as "first electric potential V**1**>third electric potential V**3**>second electric potential V**2** (GND)". Further, any pulse, which corresponds to the stabilizing pulse Ps of the individual driving signal for the large drop, does not exist in the common driving signal. In other words, the electric potential of the common electrode **45** is not changed at the timing at which the stabilizing pulse Ps is applied to the individual electrode **44**.

Further, the electric potential change (third electric potential V**3**→second electric potential V**2**) of the common electrode **45** to which the common driving signal having the common discharge pulse P**2** is output is smaller than the electric, potential change (second electric potential V**2**→first electric potential V**1**) of the individual electrode **44** to which the individual driving signal having the individual discharge pulse P**1** is output.

Further, the pulse width of the individual discharge pulse P**1** of the individual driving signal for the large drop is equal to the pulse width of the common discharge pulse P**2** of the common driving signal. Further, the timing of the individual discharge pulse P**1** is also equal to the timing of the common discharge pulse P**2**. In other words, the driver IC **64** applies the individual discharge pulse P**1** to the individual electrode **44** corresponding to the nozzle **25** for discharging the large drop, simultaneously with which the driver IC **64** applies the common discharge pulse P**2** to the common electrode **45**. Accordingly, the timing, at which the electric potential of the individual electrode **44** is changed by the application of the individual discharge pulse P**1**, is the same as the timing at which the electric potential of the common electrode **45** is changed by the application of the common discharge pulse P**2**. In FIG. **7**, the two common discharge pulses P**2** are applied so that the two common discharge pulses P**2** are synchronized with both of the two individual discharge pulses P**1** of the individual driving signal for the large drop. However, the present teaching is not limited to the complete synchronization between the individual discharge pulse P**1** of the individual driving signal for the large drop and the common discharge pulse P**2**. For example, in the example shown in FIG. **7**, one common discharge pulse P**2** may be applied so that the one common discharge pulse P**2** is synchronized with any one of the two individual discharge pulses P**1** of the individual driving signal for the large drop. In other words, when the individual driving signal for the large drop includes one individual discharge pulse P**1** or a plurality of individual discharge pulses P**1**, the common discharge pulse P**2** may be applied so that the common discharge pulse P**2** is synchronized with at least one individual discharge pulse P**1**.

Next, an explanation will be made about the deformation operation of the piezoelectric element **48** performed when the individual driving signal and the common driving signal are output from the driver IC **64** to the piezoelectric actuator **21**.

With reference to FIG. **8**, the arrows b indicate the direction of the electric field allowed to act on the piezoelectric element **48** respectively, and the arrows c indicate the deformation directions (direction of elongation or contraction) in the in-plane direction of the piezoelectric element **48**. FIG. **8** shows such a situation that the individual driving signal for the large drop shown in FIG. **7** is output to the individual electrode **44**, and the common driving signal is output to the common electrode **45**.

When the individual discharge pulse P**1** is applied to the individual electrode **44**, the electric potential of the individual electrode **44** is raised from the second electric potential V**2** to the first electric potential V**1** as shown in FIG. **8**A. Simultaneously, the common discharge pulse P**2** is applied to the common electrode **45**, and the electric potential of the common electrode **45** is conversely lowered from the third electric potential V**3** to the second electric potential V**2**. The state of the piezoelectric element **48** shown in FIG. **8**A is referred to as "first state" for the convenience of explanation,

The first electric potential V**1**, which is applied to the individual electrode **44**, is the higher electric potential of the two types of the electric potentials to be applied to the individual electrode **44**. The second electric potential V**2**, which is applied to the common electrode **45**, is the lower electric potential of the two types of the electric potentials to be applied to the common electrode **45**. Therefore, in the first state, the large electric potential difference (V**1**−V**2**) arises between the individual electrode **44** and the common electrode **45**. The strong electric field, which is directed downwardly from the individual electrode **44** to the common electrode **45**, is allowed to act on the piezoelectric element **48** interposed between the both electrodes as shown by the arrows B. Further, as shown by the arrow a, the polarization direction of the piezoelectric element **48** is also directed downwardly. Therefore, the electric field (forward electric field or positive electric field), in which the direction of the electric field is the same as the polarization direction, is allowed to act on the piezoelectric element **48**. Therefore, the piezoelectric element **48** is contracted in the in-plane direction as shown by the arrows c. When the piezoelectric element **48**, which is opposed to the central portion of the pressure chamber **26**, is contracted in the in-plane direction, then the piezoelectric member **40** is bent thereby so that the piezoelectric member **40** protrudes toward the side of the pressure chamber **26** (toward the lower side), and the piezoelectric member **40** is displaced in the downward direction at the central position of the pressure chamber **26**. The displacement amount in the downward direction of the piezoelectric member **40**, which is provided in this situation, is designated as "y**1**".

When the time, which corresponds to the pulse width of the individual discharge pulse P**1**, elapses, the electric potential of the individual electrode **44** is lowered from the first electric potential V**1** to the second electric potential V**2** as shown in FIG. **8**B. Simultaneously, the electric potential of the common electrode **45** is conversely raised from the second electric potential V**2** to the third electric potential V**3**. The state of the piezoelectric element **48** shown in FIG. **8**B is referred to as "second state" as compared with the "first state" shown in FIG. **8**A. Also in the second state, the electric potential difference (V**3**−V**2**) arises between the individual electrode **44** and the common electrode **45**. However, in this case, the electric potential of the common electrode **45** is higher than the electric potential of the individual electrode **44**. Therefore, as shown by the arrows b, the electric field, which is directed upwardly from the common electrode **45** to the individual electrode **44**, is allowed to act on the piezoelectric element **48** conversely to the situation shown in FIG. **8**A. The electric field is the electric field (reverse electric field or field reversing) which is directed reversely or oppositely to the polarization direction of the piezoelectric element **48** indicated by the arrow a. Therefore, the piezoelectric element **48** is elongated in the in-plane direction as shown by the arrows c. In this way, when the piezoelectric element **48**, which is opposed to the central portion of the pressure chamber **26**, is elongated in the in-plane direction, then the piezoelectric member **40** is thereby warped so that the piezoelectric member **40** protrudes toward the opposite side (upper side) with respect to the pressure chamber **26**, and the piezoelectric member **40** is displaced in the upward direction at the central position of the pressure chamber **26**. The displacement amount in the upward direction of the piezoelectric member **40**, which is provided in this situation, is designated as "y**2**".

As described above, the piezoelectric member **40** is displaced upwardly and downwardly between the situations provided before and after the switching of the state of the piezoelectric member **40** between the first state shown in FIG. **8**A and the second state shown in FIG. **8**B in accordance with the application of the discharge pulses P**1**, P**2**. That is, the total displacement amount y of the central portion of the piezoelectric member **40**, which is brought about between the situations provided before and after the switching between the first state and the second state, is y**1**+y**2**. The volume of the pressure chamber **26** is changed in accordance with the displacement of the piezoelectric member **40**. Accordingly, the pressure (discharge energy) is applied to the ink contained in the pressure chamber **26**, and the ink is discharged from the nozzle **25** communicated with the pressure chamber **26**.

Further, the total displacement amount y (=y**1**+y**2**) of the piezoelectric member of the embodiment of the present teaching, by which the electric potential of the common electrode **45** is changed, is larger than the displacement amount of the piezoelectric member which is provided when the electric potential of the common electrode **45** is constant. An explanation will be made below about a case in which the electric potential of the common electrode **45** is constant at the second electric potential V**2** and a case in which the electric potential of the common electrode **45** is constant at the third electric potential V**3** respectively.

<a> Case in which Electric Potential of Common Electrode **45** is Constant at Second Electric Potential V**2**.

In this case, when the electric potential of the individual electrode **44** is the first electric potential V**1**, the electric potential difference between the individual electrode **44** and the common electrode **45** is (V**1**−V**2**). Therefore, the displacement amount y in the downward direction shown in FIG. **8**A is the same as that of the embodiment of the present teaching. However, when the electric potential of the individual electrode **44** is the second electric potential V**2**, then the electric potential of the individual electrode **44** is the same as that of the common electrode **45**, and the piezoelectric element **48** is not deformed. In other words, the displacement amount y in the upward direction shown in FIG. **8**B is not generated. In other words, the total displacement amount y of the piezoelectric member **40** provided in this case is only y**1** shown in FIG. **8**A, which is smaller than the total displacement amount y provided in the embodiment of the present teaching.

<b> Case in which Electric Potential of Common Electrode **45** is Constant at Third Electric Potential V**3**

In this case, when the electric potential of the individual electrode **44** is the second electric potential V**2**, the electric potential difference between the individual electrode **44** and the common electrode **45** is (V**3**−V**2**). Therefore, the displacement amount y**2** in the upward direction shown in FIG. **8**B is the same as that of the embodiment of the present teaching. However, when the electric potential of the individual electrode **44** is the first electric potential V**1**, the electric potential difference between the individual electrode **44** and the common electrode **45** is (V**1**−V**3**) which is smaller than the electric potential difference (V**1**−V**2**) provided in the embodiment of the present teaching. Therefore, the displacement amount y**1** in the downward direction as shown in FIG. **8**A is smaller than that of the embodiment of the present teaching. As a result, the total displacement amount y is small as well.

In other words, when the electric potential of the common electrode **45** is constant, it is possible to realize only one of the increase in the displacement amount y**1** as shown in FIG. **8**A and the generation of the displacement amount y**2** as shown in FIG. **8**B. In the embodiment of the present teaching, the displacement amount y**2** in the upward direction as shown in FIG. **8**B can be also generated while increasing the displacement amount y**1** in the downward direction as shown in FIG. **8**A by changing the electric potential of the common electrode **45**. Therefore, it is possible to increase the total displacement amount y of the piezoelectric member **40**.

According to the embodiment of the present teaching as explained above, the following functions and effects are provided.

<1> The driver IC **64** outputs the individual driving signal to the individual electrode **44** corresponding to the nozzle **25** for discharging the ink, while the driver IC **64** also outputs the common driving signal to the common electrode **45** so that the electric potential of the common electrode **45** is changed in accordance with the change of the electric potential of the individual electrode **44** described above. Specifically, the individual discharge pulse P**1** is applied to the individual electrode **44**, while the common discharge pulse P**2** is applied to the common electrode **45**. Accordingly, it is possible to increase the electric potential difference between the individual electrode **44** and the common electrode **45** during the application of the individual discharge pulse P**1** to the individual electrode **44**. The deformation amount of the piezoelectric element **48** shown in FIG. **8**A is increased corresponding thereto, and the displacement amount y**1** of the piezoelectric member **40** is increased as well. Therefore, it is possible to apply the large discharge energy to the ink.

<2> The electric potential of the individual electrode **44** is the first electric potential V**1** in the first state of the piezoelectric element **48** shown in FIG. **8**A. The first electric potential V**1** is the higher electric potential of the two types of the electric potentials to be applied to the individual electrode **44**. Further, the electric potential of the common electrode **45** is the second electric potential V**2**. The second electric potential V**2** is the lower electric potential of the two types of the electric potentials to be applied to the common electrode **45**. Therefore, the electric potential difference between the individual electrode **44** and the common electrode **45** is increased, and the strong forward electric field, in which the direction of the electric field is coincident with the polarization direction, is allowed to act on the piezoelectric element **48**. On the other hand, in the second state of the piezoelectric element **48** shown in FIG. **8**B, the electric potential of the individual electrode **44** is the second electric potential V**2**, and the electric potential of the common electrode **45** is the third electric potential V**3**. In this situation, the reverse electric field, in which the direction of the electric field is opposite to the polarization direction, is allowed to act on the piezoelectric element **48**. Further, the third electric potential V**3** is the intermediate electric potential between the first electric potential V**1** and the second electric potential V**2**. Therefore, the electric potential difference between the individual electrode **44** and the common electrode **45**, which is provided in the second state, is smaller than the electric potential difference between the individual electrode **44** and the common electrode **45** which is provided in the first state. In other words, the reverse electric field, which is allowed to act on the piezoelectric element **48** in the second state, is smaller than the forward electric field which is allowed to act on the piezoelectric element **48** in the first state.

According to the above, the strong forward electric field is allowed to act on the piezoelectric element **48** in the first state shown in FIG. **8**A, the piezoelectric element **48** is greatly shrunk in the in-plane direction of the piezoelectric layer **41**, and the piezoelectric member **40** is greatly displaced in the downward direction. In addition thereto, in the second state shown in FIG. **8**B, the reverse electric field is allowed to act on the piezoelectric element **48**, the piezoelectric element **48** is elongated in the in-plane direction of the piezoelectric layer **41**, and the piezoelectric member **40** is displaced in the upward direction. Therefore, the total displacement amount of the piezoelectric element **48**, i.e., the total displacement amount y(=y**1**+y**2**) of the piezoelectric member is increased between the situations provided before and after the switching between the first state and the second state. It is possible to apply the large discharge energy to the ink contained in the pressure chamber **26**. Further, the reverse electric field, which is allowed to act on the piezoelectric element **48** in the second state, is smaller than the forward electric field which is allowed to act in the first state. Therefore, the polarization of the piezoelectric element **48** is hardly collapsed by the reverse electric field.

<3> In the embodiment of the present teaching, the pulse width of the individual discharge pulse P**1** of the individual driving signal is equal to the pulse width of the common discharge pulse P**2** of the common driving signal. Further, the application timing, at which the individual discharge pulse P**1** is applied to the individual electrode **44**, is also the same as the application timing at which the common discharge pulse P**2** is applied to the common electrode **45**. In other words, the timing, at which the electric potential of the individual electrode **44** is changed, is the same as the timing at which the electric potential of the common electrode **45** is changed. It is possible to instantaneously generate the large electric potential difference between the individual electrode **44** and the common electrode **45**. Accordingly, it is possible to greatly deform the piezoelectric element **48** in a short time, and it is possible to apply the large discharge energy to the ink contained in the pressure chamber **26**.

<4> In the embodiment of the present teaching, the driver IC **64** generates the three types of the individual driving signals corresponding to the three types of the ink discharge amounts (large drop, middle drop, small drop) respectively in order to perform the gradation printing. In general, in order to increase the amount of the ink discharged from one nozzle **25**, it is necessary to apply a large amount of discharge energy to the ink. For this purpose, it is necessary to increase the number of the individual discharge pulses P**1**. Further, when the pulse width of each of the individual discharge pulses P**1** is excessively small, then the pressure wave is hardly generated in the pressure chamber **26**, and any discharge energy is hardly applied to the ink. Therefore, it is also necessary to increase the pulse width of the individual discharge pulse P**1** to be not less than a certain value. On account of the above, the individual driving signal for the large drop, which is included in the three types of the individual driving signals and which especially provides the maximum ink discharge amount, con-

sequently has the long length, in conformity with which the discharge cycle is consequently lengthened as well.

In the meantime, when one individual driving signal, which is selected from the three types of the individual driving signals, is output to one individual electrode **44**, a problem arises such that which signal, that corresponds to any one of the three types of the individual driving signals, is the common driving signal to be output to the common electrode **45**. In relation thereto, in the embodiment of the present teaching, the common driving signal is the signal corresponding to the individual driving signal for the large drop for which it is necessary to apply the largest discharge energy to the ink. When the common driving signal is allowed to correspond to the individual driving signal for the large drop as described above, it is possible to thereby increase the displacement amount of the piezoelectric element **48** by changing the electric potential of the common electrode **45** when it is necessary to discharge the largest amount of the ink from the nozzle **25**. Accordingly, it is possible to decrease the number of the individual discharge pulses P**1** of the individual driving signal for the large drop, and/or it is possible to shorten the pulse width. It is possible to shorten the length of the individual driving signal.

An example will be explained about the shortening or reduction of the discharge cycle. It is assumed that three or more individual discharge pulses P**1** are required to be continuously applied to the individual electrode **44** in order to discharge the large drop from the nozzle **25**, when only the electric potential of the individual electrode **44** is changed as in the conventional technique. On the contrary, as described above, when the common driving signal is also output to the common electrode **45**, then the total displacement amount y of the piezoelectric member **40** is increased thereby, and it is possible to apply the larger discharge energy to the ink by applying one individual discharge pulse P**1**. Therefore, it is also possible to decrease the number of the individual discharge pulses P**1** of the individual driving signal for the large drop to be two as shown in FIG. **7**. It is possible to shorten the discharge cycle corresponding to the decrease in the number of the individual discharge pulses P**1**.

<5> The common driving signal is applied to the common electrode **45** which is provided commonly for the plurality of piezoelectric elements **48**. Therefore, the electric potential of the common electrode **45** is changed in relation to not only the piezoelectric element **48** corresponding to the nozzle **25** which discharges the ink but also the piezoelectric element **48** corresponding to the nozzle **25** which does not discharge the ink. However, the electric potential change (third electric potential V**3**→second electric potential V**2**) of the common electrode **45** is smaller than the electric potential change (second electric potential V**2**→first electric potential V**1**) of the individual electrode **44** provided when the individual driving signal is output. Therefore, in the piezoelectric element **48** corresponding to the nozzle **25** which does not discharge the ink, the electric potential difference is small even when the electric potential difference between the individual electrode **44** and the common electrode **45** is generated. Therefore, the ink is hardly discharged erroneously from the nozzle **25** which is not scheduled to discharge the ink.

Further, the common driving signal, which corresponds to the individual driving signal for the large drop, is also output to the common electrode **45** in relation to the piezoelectric element **48** corresponding to the nozzle **25** which discharges the small drop or the middle drop. However, as shown in FIG. **7**, the timing of the individual discharge pulse P**1** for the small drop is deviated from the timing of the common discharge pulse P**2** of the common driving signal. Further, the timing of the individual discharge pulse P**1** of the individual driving signal for the middle drop is deviated from the timing of the common discharge pulse P**2** of the common driving signal. In other words, the timings, at which the individual driving pulses P**1** for the small drop and the middle drop fall, are deviated from the timing at which the common discharge pulse P**2** of the common driving signal falls. Therefore, even when the electric potential of the common electrode **45** is changed in relation to the piezoelectric element **48** corresponding to the nozzle **25** for discharging the small drop or the middle drop, the electric potential change does not act so effectively on the application of the discharge energy to the ink. As described above, when the timings, at which the individual discharge pulses P**1** for the small drop and the middle drop fall, are deviated from the timing at which the common discharge pulse P**2** of the common driving signal falls, the actual discharge amount is scarcely increased in relation to the nozzle **25** which is scheduled to discharge the small drop or the middle drop, by the change of the electric potential of the common electrode **45**.

In the embodiment described above, the inkjet head **4** corresponds to the liquid discharge apparatus of the present teaching. The channel unit **20** corresponds to the channel structure of the present teaching. The driver IC **64** corresponds to the driving device of the present teaching. The first electric potential V**1** corresponds to the first high electric potential of the present teaching. The second electric potential V**2** corresponds to the first low electric potential and the second low electric potential of the present teaching. The third electric potential V**3** corresponds to the second high electric potential of the present teaching.

Next, an explanation will be made about modified embodiments in which various modifications are applied to the embodiment described above. However, those constructed in the same manner as those described in the foregoing embodiment are designated by the same reference numerals, any explanation of which will be appropriately omitted.

First Modified Embodiment

The waveforms of the individual driving signal and the common driving signal are not limited to those described in the foregoing embodiment. For example, as shown in FIG. **9**, the common driving signal may be such a signal that the electric potential of the common electrode **45** is switched between the second electric potential V**2** (GND) and a fourth electric potential V**4** which is a negative electric potential lower than the second electric potential V**2**.

Further, the common driving signal may be such that the electric potential of the common electrode **45** is changed corresponding to not only the individual discharge pulse P**1** of the individual driving signal but also the stabilizing pulse Ps. In this case, it is possible to shorten the pulse width of the stabilizing pulse Ps, and it is possible to shorten the discharge cycle thereby. In the embodiment described above, the driver IC **64** can generate the three types of the individual driving signals in accordance with the discharge amount of the ink to be discharged from the nozzle **25**. However, the number of the individual driving signals is not limited to three. The number can be appropriately changed depending on the degree of fine setting of the ink discharge amount. Alternatively, it is also allowable to use one type of the individual driving signal.

Second Modified Embodiment

The construction of the piezoelectric actuator is not limited to those described in the foregoing embodiment. For example, in the foregoing embodiment, the construction is provided such that the plurality of piezoelectric elements **48**, which are polarized in the thickness direction, exist on one piezoelectric layer **41**, and the plurality of piezoelectric elements **48** are connected with each other. However, it is also allowable that the plurality of piezoelectric elements **48** are arranged while being separated from each other.

Further, the piezoelectric actuator may have a plurality of individual electrodes corresponding to a plurality of pressure chambers **26** respectively, and two types of common electrodes. For example, a piezoelectric actuator **21**A shown in FIG. **10** has a piezoelectric member **40**A which is composed of three piezoelectric layers **41**A, **42**A, **43**A, individual electrodes **44**A, a first common electrode **45**A, and a second common electrode **46**A. The individual electrodes **44**A are arranged on the upper surface of the piezoelectric layer **41**A which is disposed at the uppermost layer. The first common electrode **45**A is arranged between the piezoelectric layer **41**A which is disposed at the uppermost layer and the piezoelectric layer **42**A which is disposed at the intermediate layer. The second common electrode **46**A is arranged between the piezoelectric layer **42**A which is disposed at the intermediate layer and the piezoelectric layer **43**A which is disposed at the lowermost layer.

The individual electrode **44**A and the first common electrode **45**A are opposed to one another while interposing the piezoelectric layer **41**A in the area overlapped with the central portion of the pressure chamber **26**. The portion of the piezoelectric layer **41**A, which is interposed between the individual electrode **44**A and the first common electrode **45**A, is referred to as "first piezoelectric element **48**A". As shown by the blanked arrow a**1** in FIG. **10**, the first piezoelectric element **48**A is polarized in the upward direction. The individual electrode **44**A and the second common electrode **46**A are opposed to one another while interposing the two piezoelectric layers **41**A, **42**A on the both sides of the first common electrode **45**A. The portions of the two piezoelectric layers **41**A, **42**A, which are interposed between the individual electrode **44**A and the second common electrode **46**A, are referred to as "second piezoelectric element **49**A". The second piezoelectric element **49**A is polarized in the downward direction.

The driver IC **64** outputs the individual driving signal to the individual electrode **44**A corresponding to the nozzle **25** for discharging the ink, while the driver IC **64** outputs the common driving signal to the first common electrode **45**A. The individual driving signal has two individual discharge pulses P**1**'. Further, the common driving signal has two common discharge pulses P**2**' corresponding to the two individual discharge pulses P**1**' respectively. The driver IC **64** outputs the individual driving signal to the individual electrode **44**A to switch the electric potential of the individual electrode **44**A between the first electric potential V**1**' and the second electric potential V**2**'. In this modified embodiment, the first electric potential V**1**' is an electric potential which is lower than the second electric potential V**2**'. Specifically, the first electric potential V**1**' is the ground electric potential (GND). On the other hand, the driver IC **64** outputs the common driving signal to the first common electrode **45**A to switch the electric potential of the first common electrode **45**A between the second electric potential V**2**' and the third electric potential V**3**' in accordance with the electric potential change of the individual electrode **44**A. The third electric potential V**3**' is an intermediate electric potential between the first electric potential V**1**' and the second electric potential V**2**'. That is, the magnitude correlation among the three types of the electric potentials is given as "second electric potential V**2**'>third electric potential>first electric potential V**1**' (GND)". The second common electrode **46**A is always maintained at the first electric potential V**1**', and the electric potential thereof is not changed.

In this modified embodiment, the second electric potential V**2**' corresponds to the first high electric potential and the second high electric potential of the present teaching. The first electric potential V**1**' corresponds to the first low electric potential of the present teaching. The third electric potential V**3**' corresponds to the second low electric potential of the present teaching.

FIG. **12** illustrates the operation of the piezoelectric actuator **21**A shown in FIG. **10**. When the individual discharge pulse P**1**' is applied to the individual electrode **44**A, and the common discharge pulse P**2**' is applied to the first common electrode **45**A, then the electric potential of the individual electrode **44**A is the first electric potential V**1**', and the electric potential of the first common electrode **45**A is the second electric potential V**2**' as shown in FIG. **12**A (first state). In the first state, as shown by the arrows b**1**, the electric field in the upward direction is allowed to act on the first piezoelectric element **48**A, and the direction of the electric field is coincident with the polarization direction of the first piezoelectric element **48**A. Therefore, as shown by the arrows c**1**, the first piezoelectric element **48**A is shrunk in the in-plane direction. Accordingly, the piezoelectric member **40**A is warped so that the piezoelectric member **40**A protrudes toward the side of the pressure chamber **26** (lower side), and the central portion thereof is displaced in the downward direction. The electric potential of the second common electrode **46**A is always the first electric potential V**1**'. Therefore, any electric potential difference arises between the individual electrode **44**A and the second common electrode **46**A. Therefore, any deformation does not arise in the second piezoelectric element **49**A.

When the time, which corresponds to the pulse width of the individual discharge pulse P**1**' elapses, then the electric potential of the individual electrode **44**A is the second electric potential V**2**', and the electric potential of the first common electrode **45**A is the third electric potential V**3**' as shown in FIG. **12**B (second state). Also in the second state, the electric potential difference arises between the individual electrode **44**A and the first common electrode **45**A. However, in this case, the electric potential of the individual electrode **44**A is higher than the electric potential of the first common electrode **45**A. Therefore, as shown by the arrows b**1**, the electric field in the downward direction is allowed to act on the first piezoelectric element **48**A inversely to FIG. **12**A, and the electric field is directed oppositely with respect to the polarization direction of the first piezoelectric element **48**A. Therefore, as shown by the arrows c**1**, the first piezoelectric element **48**A is elongated in the in-plane direction. Further, in this situation, the electric potential difference also arises between the individual electrode **44**A and the second common electrode **46**A. The electric field in the downward direction is allowed to act on the second piezoelectric element **49**A as shown by the arrows b**2**, and the electric field is coincident with the polarization direction of the second piezoelectric element **49**A. Therefore, the second piezoelectric element **49**A is shrunk in the in-plane direction.

In this way, when the electric potential of the individual electrode **44**A is switched from the first electric potential V**1**' to the second electric potential V**2**', then the first piezoelectric element **48**A is elongated in the in-plane direction as shown in FIG. **12**B from the state in which the first piezoelectric element **48**A is shrunk in the in-plane direction as shown in FIG. **12**A, while the second piezoelectric element **49**A is conversely shrunk in the in-plane direction. Accordingly, the central portion of the piezoelectric member **40**A is displaced in the upward direction.

Also in this modified embodiment, the electric potential of the first common electrode **45**A is changed in accordance with the change of the electric potential of the individual electrode **44**A in the same manner as in the embodiment described above. Therefore, the electric potential difference between the individual electrode **44**A and the first common electrode **45**A is increased with reference to FIG. **12**A as compared with a case in which the electric potential of the first common electrode **45**A is constant at the third electric potential V**3**'. Therefore, the amount of contraction in the in-plane direction of the first piezoelectric element **48**A is increased, and the amount of displacement in the downward direction of the piezoelectric member **40**A is increased. Further, the electric potential difference arises between the individual electrode **44**A and the first common electrode **45**A with reference to FIG. **12**B as well, and hence the upward displacement arises in the piezoelectric member **40**A, as compared with a case in which the electric potential of the first common electrode **45**A is constant at the second electric potential V**2**'. In any case, the total displacement amount of the piezoelectric member **40**A is increased as compared with any situation in which the electric potential of the first common electrode **45**A is constant.

Third Modified Embodiment

In the embodiment described above, the following construction is provided. That is, the piezoelectric layers **41**, **42** are arranged while ranging over the plurality of pressure chambers and the plurality of individual electrodes **44**, and the plurality of piezoelectric elements **49**, which correspond to the plurality of pressure chambers **26** respectively, are connected with each other. On the contrary, it is also allowable to provide such a construction that the plurality of piezoelectric elements **49**, which are arranged corresponding to the plurality of pressure chambers **26** respectively, are separated from each other. The method for forming the plurality of piezoelectric elements **49** is not limited to the method in which the green sheets are sintered as exemplified in the embodiment described above. For example, the plurality of piezoelectric elements **49**, the plurality of individual electrodes **44**, the common electrode **45**, and other components can be formed by forming films on a silicon substrate.

In the embodiment and the modified embodiments thereof explained above, the present teaching is applied to the inkjet head for printing, for example, an image by discharging inks onto the recording paper. However, the present teaching is also applicable to any liquid discharge apparatus to be used for various ways of use other than the printing of the image or the like. For example, the present teaching can be also applied to a liquid discharge apparatus for jetting a conductive liquid onto a substrate to form a conductive pattern on a surface of the substrate.

What is claimed is:

1. A liquid discharge apparatus configured to discharge liquid, comprising:

a channel structure in which a plurality of liquid channels including a plurality of nozzles is formed;

a piezoelectric actuator which is formed on the channel structure and which is configured so that discharge energy is applied to the liquid contained in the nozzles to discharge the liquid from the plurality of nozzles respectively, the piezoelectric actuator including:

a plurality of individual electrodes which correspond to the plurality of nozzles respectively and each of which is configured to be subjected to an electric potential, separately;

a common electrode which is configured to be subjected to a common electric potential; and

a piezoelectric layer which is sandwiched between each of the individual electrodes and the common electrode; and

a driving device which is configured to drive the piezoelectric actuator, the driving device being configured so that:

an individual driving signal, which causes a change of an electric potential of the individual electrodes, is output to each of the individual electrodes corresponding to one of the nozzles for discharging the liquid; and

a common driving signal, which causes a change of an electric potential of the common electrode in synchronization with the change of the electric potential of the individual electrodes into which the individual driving signal is input, is output to the common electrode;

wherein portions of the piezoelectric layer sandwiched between the individual electrodes and the common electrode are polarized in a polarization direction;

wherein the individual driving signal is such a signal that the electric potential of the individual electrode is switched between a first electric potential and a second electric potential;

wherein the common driving signal is such a signal that the electric potential of the common electrode which is provided when the electric potential of the individual electrode is the first electric potential, is allowed to be the second electric potential, and that the electric potential of the common electrode, which is provided when the electric potential of the individual electrode is the second electric potential, is allowed to be a third electric potential which is intermediate between the first electric potential and the second electric potential;

wherein an electric field which has a direction coincident with the polarization direction, is allowed to act on the portions of the piezoelectric layer in a case that the portions of the piezoelectric layer are in a first state in which the electric potential of the individual electrode is the first electric potential and the electric potential of the common electrode is the second electric potential; and

wherein an electric field, which has a direction opposite to the polarization direction, is allowed to act on the portions of the piezoelectric layer in a case that the portions of the piezoelectric layer are in a second state in which the electric potential of the individual electrode is the second electric potential and the electric potential of the common electrode is the third electric potential.

2. The liquid discharge apparatus according to claim **1**;

wherein an amount of the change of the electric potential of the common electrode brought about when the common driving signal is output is smaller than an amount of the change of the electric potential of the individual electrode brought about when the individual driving signal is output.

3. The liquid discharge apparatus according to claim **1**;

wherein the electric potential of the individual electrode into which the individual driving signal is input is switched between a first high electric potential and a first low electric potential which is lower than the first high electric potential;

wherein the electric potential of the common electrode into which the common driving signal is input is switched between a second high electric potential and a second low electric potential which is lower than the second high electric potential; and

wherein the electric potential of the common electrode is the second low electric potential in a case that the electric potential of the individual electrode is the first high electric potential.

4. The liquid discharge apparatus according to claim **1**;

wherein the individual driving signal has an individual discharge pulse which changes the electric potential of the individual electrode in order to apply the discharge energy to the liquid contained in the nozzle;

wherein the common driving signal has a common discharge pulse which changes the electric potential of the common electrode corresponding to the individual discharge pulse; and

wherein an electric potential difference between the individual electrode and the common electrode is increased when the individual discharge pulse is applied to the individual electrode and the common discharge pulse is applied to the common electrode as compared with when only the individual discharge pulse is applied to the individual electrode.

5. The liquid discharge apparatus according to claim **4**;

wherein a pulse width of the individual discharge pulse is equal to that of the common discharge pulse; and

wherein the driving device applies the individual discharge pulse to the individual electrode, simultaneously with which the driving device applies the common discharge pulse to the common electrode.

6. The liquid discharge apparatus according to claim **1**;

wherein the driving device is configured so that a plurality of types of the individual driving signals, which correspond to a plurality of liquid discharge amounts respectively, are generated, the driving device being configured so that one of the plurality of types of the individual driving signals is selected and output to one of the individual electrodes corresponding to one of the nozzles for discharging the liquid; and

wherein the common driving signal is a signal which changes the electric potential of the common electrode in accordance with a change of the electric potential of the one of the individual electrodes provided when the individual driving signal corresponding to the largest liquid discharge amount is input.

7. The liquid discharge apparatus according to claim **6**;

wherein the individual driving signal corresponding to the largest liquid discharge amount includes at least one individual driving pulse; and

wherein the common driving signal includes at least one common driving signal pulses which is synchronized with one of the at least one individual driving pulses.

8. The liquid discharge apparatus according to claim **7**;

wherein a number of the at least one common driving signal pulses is the same as a number of the at least one individual driving pulses, and each of the at least one common driving signal pulses is synchronized with one of the at least one individual driving pulses.

9. A liquid discharge method for discharging liquid by using a liquid display apparatus;

wherein the liquid display apparatus comprises:

a channel structure in which a plurality of liquid channels including a plurality of nozzles is formed; and

a piezoelectric actuator which is formed on the channel structure and which is configured so that discharge energy is applied to the liquid contained in the nozzles to discharge the liquid from the plurality of nozzles respectively, the piezoelectric actuator including:

a plurality of individual electrodes which correspond to the plurality of nozzles respectively and each of which is configured to be subjected to an electric potential, separately;

a common electrode which is configured to be subjected to a common electric potential; and

a piezoelectric layer which is sandwiched between each of the individual electrodes and the common electrode; and

wherein the method comprises:

outputting an individual driving signal which causes a change of an electric potential of the individual electrodes, to each of the individual electrodes corresponding to one of the nozzles for discharging the liquid; and

outputting a common driving signal which causes a change of an electric potential of the common electrode in synchronization with the change of the electric potential of the individual electrodes into which the individual driving signal is input, to the common electrode.

10. A liquid discharge apparatus configured to discharge liquid, comprising:

a channel structure in which a plurality of liquid channels including a plurality of nozzles is formed;

a piezoelectric actuator which is formed on the channel structure and which is configured so that discharge energy is applied to the liquid contained in the nozzles to discharge the liquid from the plurality of nozzles respectively, the piezoelectric actuator including:

a plurality of individual electrodes which correspond to the plurality of nozzles respectively and each of which is configured to be subjected to an electric potential, separately;

a common electrode which is configured to be subjected to a common electric potential; and

a piezoelectric layer which is sandwiched between each of the individual electrodes and the common electrode; and

a driving device which is configured to drive the piezoelectric actuator by:

outputting an individual driving signal, which causes a change of an electric potential of the individual electrodes, to each of the individual electrodes corresponding to one of the nozzles for discharging the liquid; and

outputting a common driving signal to the common electrode, which causes a change of an electric potential of the common electrode in synchronization with the change of the electric potential of the individual electrodes into which the individual driving signal is input.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,216,571 B2
APPLICATION NO. : 14/455140
DATED : December 22, 2015
INVENTOR(S) : Kyohei Naito et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the claims,

At column 19, claim number 9, line number 2
"using a liquid display apparatus;"

should read:
--using a liquid discharge apparatus;--

At column 19, claim number 9, line number 3
"wherein the liquid display apparatus comprises:"

should read:
--wherein the liquid discharge apparatus comprises:--

Signed and Sealed this
Twenty-sixth Day of April, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office